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SOVIET RESEARCH REACTORS

VVR-M (LENINGRAD) AND VVR-M (KIYEV)

Summary of Data

AID Work Assignment No. 31
(Report No. 7 in this Series)

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FOREWORD

This is the seventh in a series of reports on Soviet research reactors. The first three reports in this series (AID Reports 62-43, 62-127, and 62-172) were prepared in response to AID Work Assignment No. 16. The fourth, fifth, and sixth reports (AID Reports 62-197, P-63-14, and P-63-53) were prepared in conformance with AID Work Assignment No. 31, as was the present report.

This report provides a description of two Soviet water-moderated, water-cooled reactors (VVR-M), one of which is located in Leningrad and the other in Kiyev. These VVR-M reactors were developed from the prototype VVR-M reactor described in reference [1]. Background information, general construction details, features of the control and safety systems, heat transfer characteristics, reactor physics, and the experimental facilities afforded by the reactor are presented. The report is illustrated with cross-section views, photographs, and diagrams of the reactor and auxiliary equipment. The report is based on Soviet open literature available at the Aerospace Information Division and the Library of Congress. Any further information concerning these reactors will be published in the form of supplements to this report, as soon as it becomes available.

A list of references cited accompanies the text. Library of Congress call numbers are given at the end of the source entry when the source is available at the Library of Congress.

I. THE LENINGRAD AND KIYEV VVR-M REACTORS

1. Background

The VVR-M type water-moderated, water-cooled research reactors are intended for the production of radioactive isotopes with high specific activities and the production of transuranic elements. They are also designed for studying neutron physics, the effects of neutrons and gamma-rays on materials, neutron-diffraction, and the like. They operate at a power of 10,000 kw and a neutron flux of $\sim 10^{14}$ neutron/cm²·sec. The core is surrounded by a metallic-beryllium reflector and has nine horizontal neutron beam tubes and eleven horizontal channels for irradiation of specimens. [1] One such reactor was put into operation at the Leningrad Physicotechnical Institute, Academy of Sciences USSR, in December 1959 [2], and the other at the Institute of Physics, Academy of Sciences Ukrainian SSSR, in Kiyev, in February 1960 [3]. The following personalities are associated with the development of the VVR-M type reactors: L. I. Rusionov, Yu. G. Nikolayev, V. A. Shustov, G. V. Skornyakov, S. M. Feynberg, A. M. Glukhov, P. P. Moiseyenko, K. A. Konoplev, and Yu. V. Petrov [1].

2. General Construction

The principal flow diagram and a vertical cross-section of the VVR-M type reactor are given in Figs. 1 and 2.

Fuel Elements

Each fuel element consists of one hexahedral tube and two cylindrical tubes arranged axially and fastened mechanically. The tubes consist of Al + UO₂ cermet covered with aluminum (see Fig. 3). The cermet layer is 0.9 mm thick and the aluminum layer is 0.7 mm thick. The active length of the fuel element is 500 mm. Cooling water flows through the spaces between the fuel element tubes. For convenience in recharging the lattice, the fuel elements are combined to form fuel assemblies, each of which consists of three fuel elements. [1]

Reactor Core

The core of the reactor (see Figs. 4 and 5) is located near the bottom of an aluminum tank under a layer of water 3.5 m deep. The core has a hexagonal cross-section with an inscribed diameter of 540 mm, and is 500 mm high. The lower ends of the fuel assemblies are inserted into the lower grid of the core. There is no upper grid; its place is taken by regularly spaced protrusions at the upper ends of the fuel elements, which form spaces between the sections. A maximum of 263 fuel elements can be loaded into the

[Text resumes on p. 6.]

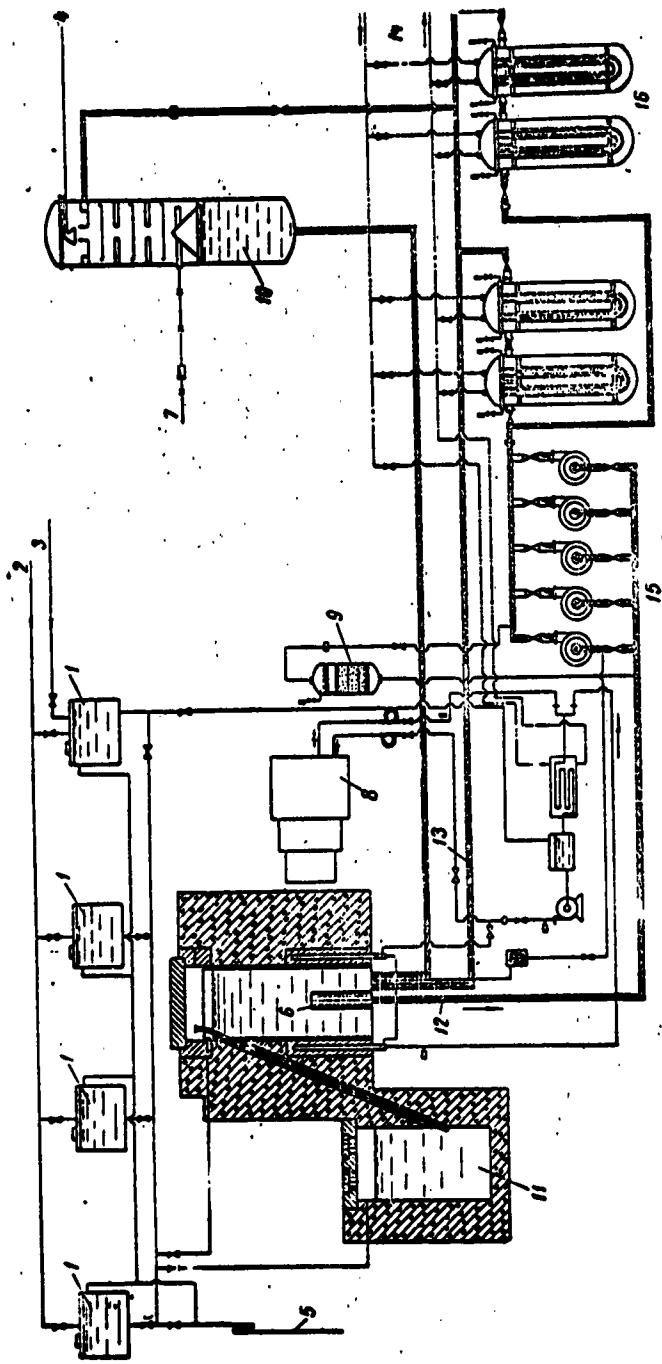


Fig. 1. Principal flow diagram of the VR-M reactor [1]

1 - distillate tanks; 2 - distillate tanks; 3 - process water; 4 - outlet to ventilating system; 5 - overflow to drainage; 6 - core; 7 - air from main hall; 8 - thermal column; 9 - ion exchange filter; 10 - deaerator; 11 - filter; 12 - storage tank; 13 - distillate outlet; 14 - heat exchanger; 15 - circulation pumps; 16 - heat exchangers.

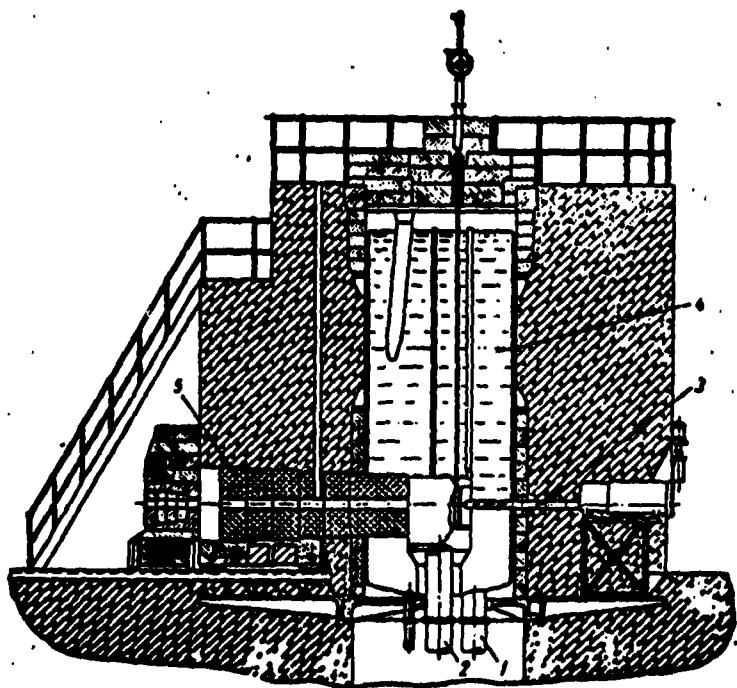


Fig. 2. Vertical cross section of the VVR-M reactor [1]

1 - water inlet; 2 - water outlet; 3 - horizontal beam tube;
4 - tank containing reactor core; 5 - thermal column.

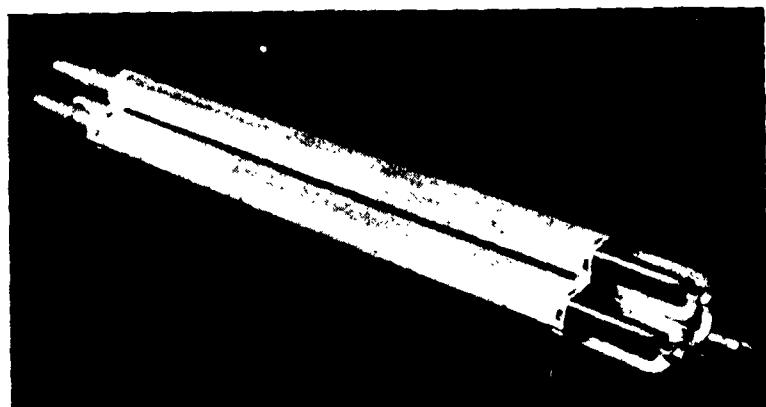


Fig. 3. Fuel assembly composed of three fuel elements [1]

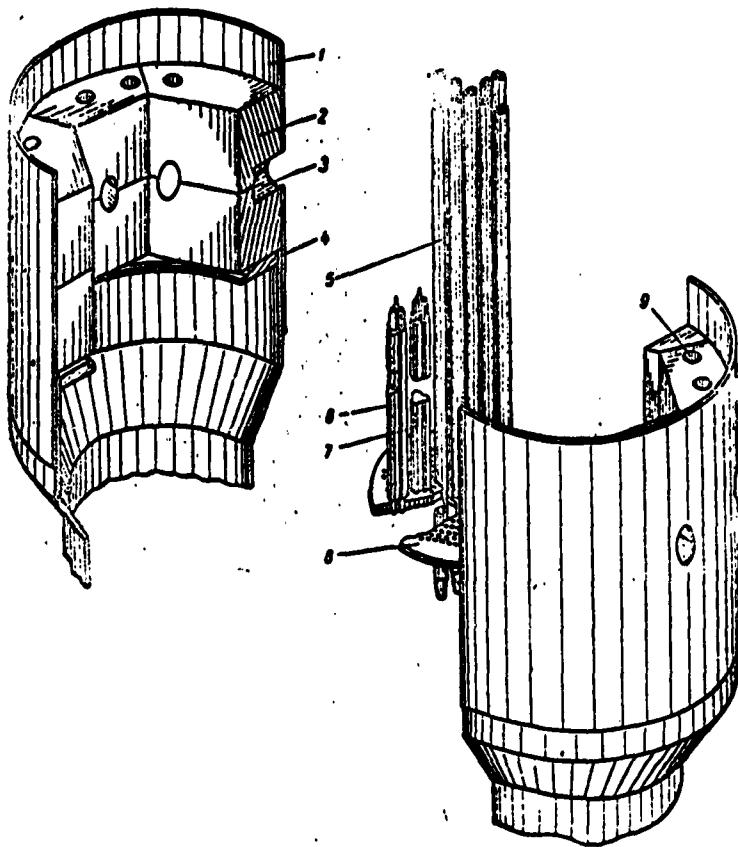


Fig. 4. Exploded view of the reactor core [1]

1 - shell housing core; 2 - reflector assembly; 3 - horizontal beam tube opening; 4 - flange supporting reflector; 5 - safety and control rod channels; 6 - fuel assembly; 7 - beryllium rod shaped like fuel assembly; 8 - lower grid of core; 9 - vertical experimental channel opening.

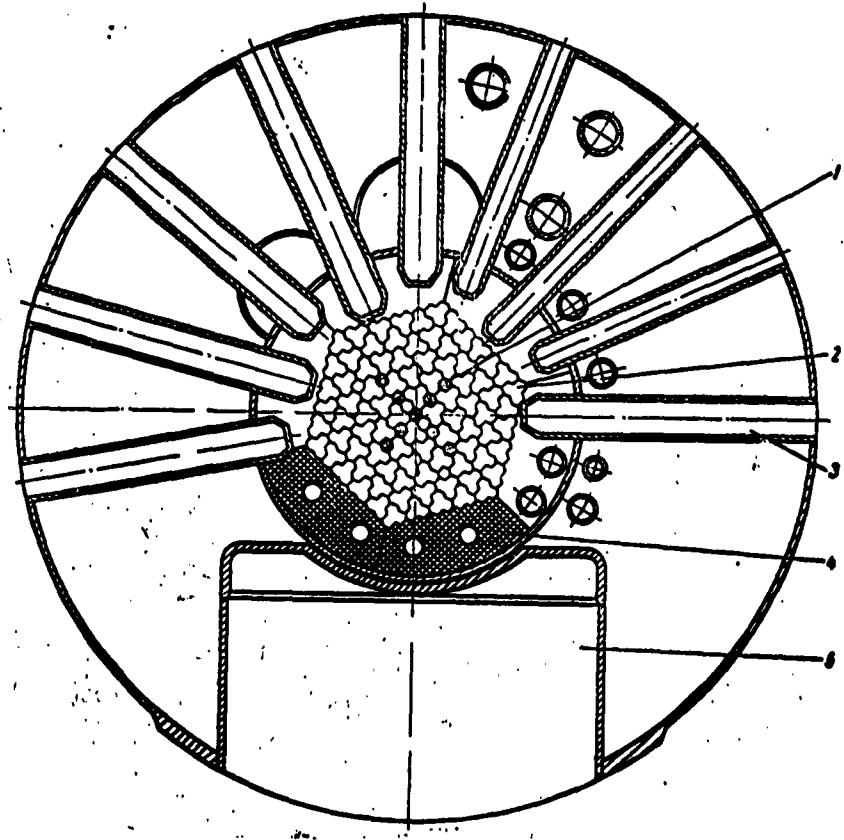


Fig. 5. Horizontal cross section of reactor core [1]

1 - safety and control rod channels; 2 - fuel assembly;
3 - horizontal beam tube; 4 - beryllium reflector; 5 -
thermal column.

core. In the center of the core there are nine passages for control and safety rods. When the reactor is not fully loaded, the empty spaces in the lattice are filled with beryllium rods shaped just like the fuel elements (see Fig. 6). The flexibility of this arrangement of the core makes it possible to give the core any desired shape within the limits of its physical dimensions, to increase the local neutron flux in any of the experimental channels, and to create temporary channels for irradiating specimens within the core itself. [1]



Fig. 6. Beryllium rod for replacing fuel elements in the core [1]

Core Parameters [1]

Portion of the volume of the core occupied by water	0.6
U^{235} concentration	52 g/l
Wall thickness of hexagonal or cylindrical tube	2.3 mm
Thickness of $Al + UO_3$ cermet layer	0.9 mm
Thickness of aluminum coating on cermet layer	0.7 mm
Width of spaces between fuel element tubes	3 mm
Amount of U^{235} in a fuel element	27.6 g
Number of fuel elements constituting full load	268
Number of control and safety rods	9

Beryllium Reflector

The reactor core is surrounded by a metallic beryllium reflector. The reflector is cylindrical with a hexagonal cavity containing the core (Fig. 7). To achieve a better fit between core and reflector, recesses shaped like the fuel elements are machined in the walls of the cavity. The outermost fuel elements are separated from the beryllium reflector by a layer of water only 3 mm thick. The reflector has nine horizontal beam tubes directing neutron beams to the experimental hall, and 11 vertical channels for irradiating specimens. Two additional openings are provided for hooking up experimental loops. There are vertical channels 6 mm in diameter all around the reflector for the passage of the water coolant, which

amounts to 2.5% of the volume of the reflector. The construction of the reflector is such that it can be assembled and disassembled under water. [1]

The use of beryllium as a reflector makes it possible to lower the thermal power of the reactor without decreasing the neutron flux in the core, thereby economizing fuel. In addition, the beryllium reflector makes it possible to obtain a flash-up of thermal neutron flux in the vicinity of the experimental channels. [1]

Shielding

The main shielding of the reactor ensures a low level of background radiation in the main control room. The side shielding consists of a water layer 65 cm thick, a layer of pig iron 20 cm thick, and a layer of concrete 230 cm thick. The concrete has a specific weight of 3.2 g/cm³.

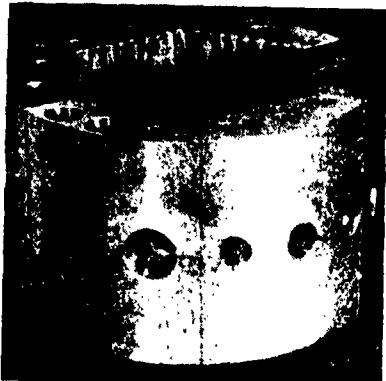


Fig. 7. Beryllium reflector [1]
power level. [1]

According to calculations, at a power level of 10,000 kw the fast neutron flux at the surface of the shielding will be less than $3 \cdot 10^{-3}$ n/cm²·sec and the gamma-ray flux will be less than $3 \cdot 10^{-1}$ kv/cm²·sec.

On top the reactor is shielded by 350 cm of water and 80 cm of pig iron. Although reloading the core requires removal of the pig iron shielding, the 350-cm water layer reduces the gamma-radiation from the core to 3.7 μ r/sec, even after prolonged operation at the 10,000-kw

All nine of the horizontal beam tubes are safely closed by beam tube shielding plugs. Discharge into the atmosphere of radioactive waste is brought about by the activation of air passing through internal spaces where there is a high neutron flux (e.g., vertical channels, beam tubes, thermal column, etc.). According to calculations, up to 7 cu/hr of radioactive argon may be expelled. However, if the internal spaces (i.e., experimental channels, etc.) are hermetically sealed, the discharge of radioactive argon drops to 0.5 cu/hr. Radioactive aerosols formed in the hot cells during the removal of irradiated specimens are not discharged into the atmosphere, but are caught by a filter. Hot cell operation data give the following values for the formation of radioactive aerosols: Sr⁹⁰, 10^{-3} cu/24 hr; Ba¹⁴⁰ - La¹⁴⁰, $0.5 \cdot 10^{-3}$ cu/24 hr; and Sr⁹⁰ - Y⁸⁸, $0.3 \cdot 10^{-4}$ cu/24 hr. [1]

Radioactive gases formed during reactor operation are vented into the atmosphere through a ventilation stack 60 m high. Calculation shows the maximum concentration of radioactive gases and aerosols at ground level to be $2.5 \cdot 10^{-18}$ cu/l. [1]

3. Heat Transfer

The core is cooled by water flowing from top to bottom under a head pressure of 3.5 m. Water is circulated through the loop by four parallel-connected pumps. The amount of water flowing through the core varies with the number of fuel elements loaded in the reactor. The maximum rate of flow through the core is limited by the hydraulic losses in the inlet part of the loop with small and medium loads, and by the total resistance of the loop with large loads. Figure 8 shows the dependence of maximum water flow rate on the load, calculated from the hydraulic parameters of the circulation loop. [1]

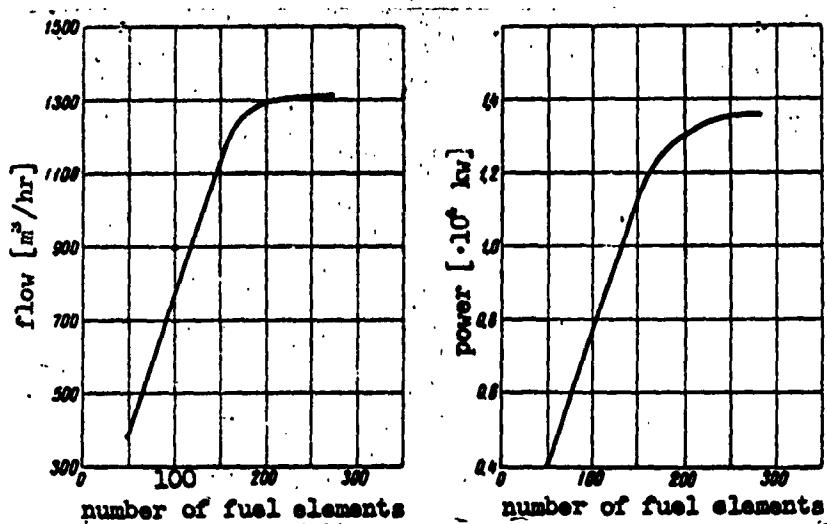


Fig. 8. Rate of water flow through core of reactor [1]

Fig. 9. Dependence of reactor power level on loading [1]

The thermal power of the reactor is limited by the fuel element surface temperature causing the water coolant close to the fuel element wall to boil. Figure 9 shows the dependence of maximum power on load for a fuel element wall temperature of 95°C. The effective coefficient of heat release imbalance in the core, taking into account both mechanical factors and the local rise in neutron density, was equal to 2. The distillate temperature varies with the power level between 24° and 36°C at the core inlet and between 32° and 45°C at the core outlet. A part of the distillate is circulated through the beryllium reflector to keep its temperature below 60°C. [1]

The heat released in the core is transferred by four heat exchangers (see Fig. 1, page 2) to the process water of the secondary loop. The process water flow rate is $1000 \text{ m}^3/\text{hr}$, and its temperature at the heat exchanger inlet is 18°C . [1]

4. Reactor Physics

The reactor uses ordinary water as moderator and coolant, and 20% enriched uranium as fuel. Selection of the enrichment was governed by the technological feasibility of producing elements with a highly developed surface. [1]

The maximum thermal flux in the core at the nominal power of 10,000 kw is at least $10^{14} \text{ n/cm}^2 \cdot \text{sec}$. The intensity of the total neutron flux at the exits from the beam tubes is

from $2 \cdot 10^9$ to $3 \cdot 10^9 \text{ n/cm}^2 \cdot \text{sec}$. The design of the reactor provides considerable flexibility in the arrangement of the core. The substitution of beryllium rods for fuel elements in the core makes it possible to start the run with a small fuel load, subsequently increasing the number of fuel elements in the core as burnup proceeds. At the same time, increasing the volume of the core at the end of the run makes it possible to achieve a significant degree (-25%) of fuel burnup. If a fast neutron flux is needed in the beam tubes at the beginning of the run, some of the beryllium rods near the beam tubes in question can be replaced by fuel elements. The distribution of the neutron flux in the reactor at the beginning of a run is shown in Fig. 10. [1]

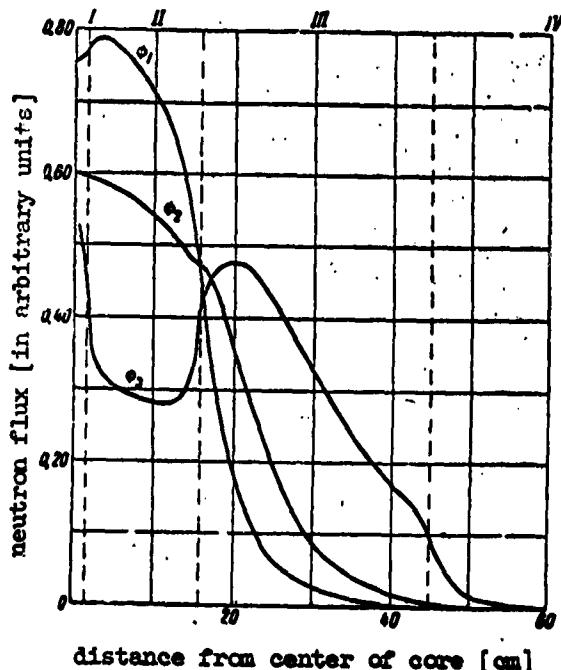


Fig. 10. Distribution of neutron flux in the reactor (at beginning of run) [1]

Φ_1 - fast neutron flux; Φ_2 - intermediate neutron flux; Φ_3 - thermal neutron flux. Control rod PP_1 withdrawn from core. I - channel for control rod PP_1 ; II - core; III - beryllium reflector; IV - water.

5. Control and Safety Systems

The reactor control and safety systems were designed for normal reactor operation with thermal loads close to the permissible maximum. Control rod effectiveness (see Table 1) is sufficient to compensate the reactivity losses due to prolonged operation at a thermal neutron flux of $\sim 10^{14}$ n/cm²·sec. [1]

Table 1. Efficiency ($\Delta k/k$) of control rods (calculated) [1]

Nomenclature of rods	PP ₁ (center of core)	PP ₂ (taken singly)	IIP or PP ₁ (peripheral)	A3	AP	Total efficiency	
						AP and PP	A3
Beginning of run	0.06	0.06	0.06	0.04	0.005*	0.30	0.12
Fully loaded	0.018	0.013	0.012	0.016	0.005	0.073	0.048

* During underloading at beginning of run the AP rod diameter must be 10 mm.

The reactor has the following excess reactivity: [1]

Xe ¹³⁵ and Sm ¹⁴⁹ poisoning	5%
Temperature effect	1%
Physical experiments	2%

Fuel burnup, reactor slagging with small diameter fission products, and partial poisoning by Sm¹⁴⁹ are compensated by a supplementary load of fuel elements. The control system consists of nine rods with a total compensating capacity between 40% and 12%, depending on the run period. [1]

Data on individual rods is given in Table 2.

Table 2. Control and safety rods, VVR-M reactor [1]

Nomenclature of Rod*	Number of Rods	Purpose	Material
PP ₁	2	Manual control	Boron carbide
PP ₂	2	Manual control	Boron carbide
IIP	1	Precision control	Boron carbide
AP	1	Automatic control	Steel
A3	3	Safety system	Boron carbide

* The diameter of absorbers in all rods is 25 mm.

Ionization chambers with boron-coated electrodes are used as the sensors of the control and safety systems. The automatic control system makes it possible to maintain a given reactor power level with an accuracy of $\pm 1.5\%$. The rate of rod withdrawal is chosen so that should the automatic control system malfunction and all control rods be withdrawn simultaneously at their usual rates, the safety system would be triggered before a power excursion could occur. Additional protection is provided based on the neutron flux buildup period. The time elapsed from the moment of appearance of an emergency signal to activation of the safety system does not exceed 1 sec. [1]

6. Experimental Facilities

The VVR-M research reactors are provided with nine horizontal beam tubes and 11 channels for specimen irradiation. At a power level of 10,000 kw the reactor has a maximum neutron flux $> 10^{14}$ n/cm²·sec. [1]

II. THE LENINGRAD VVR-M REACTOR

Startup and Applications

A general view of the Leningrad VVR-M Reactor belonging to the Physicotechnical Institute, Academy of Sciences USSR, is given in Fig. 11 [4]. This reactor was completed and put into operation in December 1959 [2]. It is designed for research in the fields of nuclear physics, solid-state physics, radiochemistry, metallurgy, and nuclear energy, and on the use of radioactive isotopes in industry, and for the investigation of a number of problems in the fields of biology and agriculture [2].

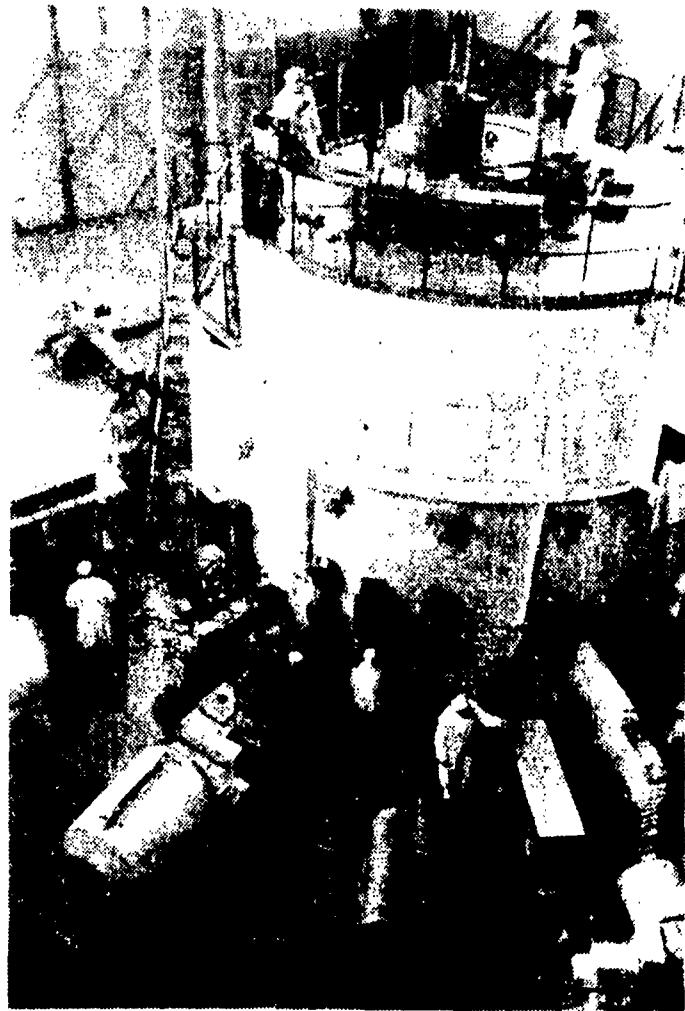


Fig. 11. View of the VVR-M reactor belonging to the Leningrad Physicotechnical Institute of the Academy of Sciences USSR [4]

III. THE KIYEV VVR-M RESEARCH REACTOR

1. Startup and Applications

The Kiev VVR-M research reactor belonging to the Institute of Physics, Academy of Sciences Ukrainian SSR, was put into operation in February 1960. A general view of this reactor is given in Fig. 12. [3]

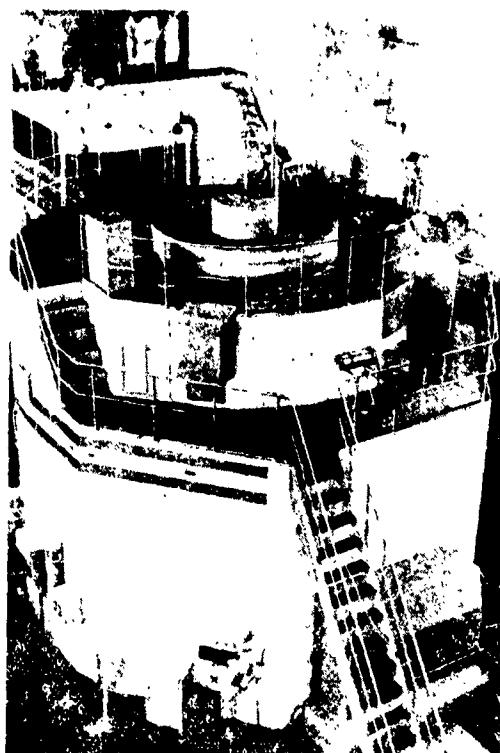


Fig. 12. View of the VVR-M reactor belonging to the Institute of Physics of the Academy of Sciences Ukrainian SSR in Kiev [3]

2. Research Conducted With the Reactor

In order to discover the effect of irradiation on the properties of CdS monocrystals, A. P. Galushka and I. D. Konozenko irradiated $4 \times 2 \times 1$ -mm CdS specimens, which had first been heated for 1 hr to 600°C , in the vertical channels of the reactor. Total neutron doses (including fast and thermal neutrons) of 10^{12} , 10^{14} , 10^{16} , and 10^{18} n/cm^2 were used. Irradiation took place at 50°C . Their paper was submitted for publication in November 1961. [6]

According to source [3], published in April 1960, the following research was scheduled to be performed with this reactor: 1) M. V. Pasechnik, V. P. Vertebniy, and R. G. Ofengenden are to conduct a study of resonant scattering of slow neutrons by the time-of-flight method (a special mechanical selector and 1024-channel time analyzer were made for this purpose). 2) M. V. Pasechnik and M. F. Barchuk are to investigate capture gamma-ray spectra (a wide angle gamma-spectrometer, with a capture angle of up to 80° , was built). 3) Lifetimes of short-lived isotopes are to be studied (no names of personalities mentioned). [3]

In addition, unspecified studies will be conducted in the fields of radiochemistry and radiobiology [3], and in physics, chemistry, agrobiology, physiology, and microbiology [5].

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